Syn-Aud-Con Tech Topic

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Is there anything special about hooking an amplifier to a loudspeaker? Here is a brief look at some parameters that can affect the sonic performance of this important interface.

The Ideal Case

Most analog interconnects in a sound reinforcement system are of the constant-voltage type, meaning that a low impedance output is used to drive a high impedance input. The result is the maximum transfer of the voltage component of the audio signal and minimal current transfer. Such interfaces are not optimized for power transfer, which requires that the circuit impedances be matched. Ironically, the amplifier/loudspeaker interface is of the constant-voltage type.

This may at first seem counter-intuitive. After all it *is* a *power* amplifier. Constant voltage interfaces deliver sufficient power to the loudspeaker load, while maintaining good stability and minimizing the effects of the loudspeaker cable.

The rule-of-thumb followed when interfacing line level audio equipment is to maintain a 1-to-10 ratio between output and input impedances. This is sufficient to prevent an input from loading an output (causing a voltage drop), and provides the additional benefit of making the output voltage of a component independent of the load impedance. When loaded in this manner, a further increase in input impedance does not yield better voltage transfer. Current transfer under these conditions is minimal (but not non-existent!) and there is little danger of the driving device not meeting the current requirements of the driven device.

This is a good place to inject an example. Consider a large dam and hydroelectric power station. When the gates are closed, the turbines do not move, and the dam is under great pressure from the weight of the water. When the gates are opened, the turbines are driven by the escaping water, yet the pressure on the dam is relatively unchanged. This can be considered analogous to the

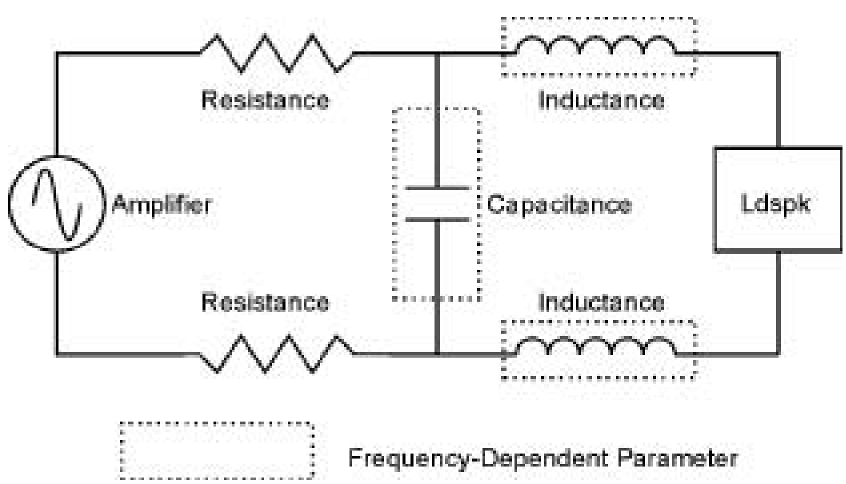

Figure 1 - The equivalent circuit of a cable as seen by the amplifier and loudspeaker. The affects of both capacitance and inductance vary with frequency, and must be considered within the audible passband of the system.

constant-voltage interface between amplifier and loudspeaker. Constant voltage (pressure) can be maintained while still developing significant power and maintaining a current (water flow) reserve.

The Loudspeaker Cable

Much attention is given to the cable connecting the amplifier and loudspeaker. This is a vital system component, and its effects must be considered. Figure 1 shows an equivalent circuit of a loudspeaker cable. It contains a series resistance (both send and return), a parallel capacitance, and a series inductance in each leg of the circuit. The value of the resistance is independent of frequency. The values of the inductive and capacitive reactances are frequency-dependent, so we must perform some simple calculations to determine *if* and *when* they become significant. Some practical guidelines are required to continue. Let us assume that the reactive parameters become significant when the level change caused by their presence approaches 1 dB at any frequency within the bandwidth of the human hearing system. This will happen when their reactances rise to approximately one-tenth the value of the loudspeaker's impedance. An impedance of 4 ohms will be considered, since this represents (hopefully) a worst-case scenario of the actual impedance of a loudspeaker with an 8 ohm rating.

$$\Delta dB = 20\log\frac{4}{4+\frac{4}{10}}$$

$$\Delta dB = 0.8$$

level change caused by reactance reaching one-tenth of the loudspeaker impedance

Cable Capacitance

Since the capacitance is in parallel with the amplifier and load, as frequency increases it will eventually form a short circuit around the loudspeaker. The required capacitance for the roll-off to just become audible is

$$C = \frac{1}{2\pi f\,(Z_{\min})(10)}$$

$$= \frac{1}{2\pi\ 20(10^3)40}$$

$$\approx 0.2\,ufd$$

How much wire is required to accumlate this much capacitance. At 50 pF/ft (a high figure for loudspeaker wire), the required length becomes

$$Length = \frac{0.2(10^{-6})}{50(10^{-12})}$$

$$= 4{,}000\ ft$$

The effects of cable capacitance in a loudspeaker circuit are not likely to produce an audible effect.

Cable Inductance

Wire also has inductance. A series inductance will form a low-pass filter between the amplifier and loudspeaker. The highest frequency of interest (20 kHz) will be most affected by the presence of an inductance. The inductance required to just make an audible change is

$$L = \frac{X_L}{2\pi f}$$

$$L = \frac{0.4}{2\pi\ (20)(10^3)}$$

$$L \approx 3.2\,uH$$

Calculating the inductance of a straight piece of wire is not trivial, but can be approximated by[1]

$$L = 0.00508l\left(\ln\frac{2l}{r}\right) - 0.75$$

where
l is wire length in inches
r is the wire radius in inches

Assuming a wire radius of 0.035" (AWG16) we can perform a few iterations to find how long the wire would need to be to form a 3.2 uH series inductor.

$$3.2(10^{-6}) = 0.00508l\left[\left(\ln\frac{2l}{0.035}\right) - 0.75\right]$$

$$l \cong 80\,in$$

This represents a worst case. In practice other factors can affect the results, such as conductor spacing, coiling, etc. It does serve to make the point that if wire length is kept short and wires are not coiled cable inductane can prove negligible.

Neglecting the effects of capacitance and inductance, the circuit of Figure 1 simplifies to the following

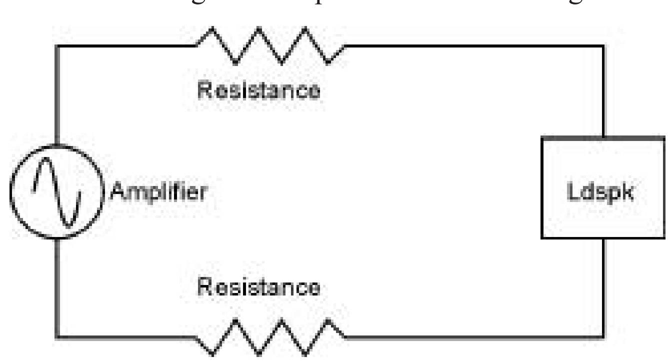

Figure 2 - Simplified circuit of a loudspeaker cable.

Cable Resistance

The resistance of the wire increases with length, decreases with increased conductor cross-sectional area, and is independent of frequency. As the resistance of the wire increases, the current flowing in the circuit is reduced. This reduces the current flow through the loudspeaker which reduces the voltage drop across the loudspeaker and results in a drop in sound level. The effect is commonly referred to as *line loss*. Those familiar with electronics will recognize the circuit as a voltage divider. In this voltage divider circuit the losses due to wire resistance can be minimized by keeping this parasitic resistance of the wire small relative to the impedance of the loudspeaker.

The Five-Percent Rule

Common practice among system designers is to design for a wire resistance of no more than 5% of the loudspeaker's minimum impedance. Using the example of a 4 ohm loudspeaker, the maximum tolerable wire resistance becomes

$$\begin{aligned} R_{\max} &= 4(0.05) \\ &= 0.2\, ohms \end{aligned}$$

Any combination of wire length and area can be used as long as the loop resistance does not exceed this value. Figure 3 shows the resistance per unit of some common wire gauges.

AWG	R per foot	R per meter	mm²
8	0.000628	0.002060	8.36
10	0.000999	0.003277	5.26
12	0.001588	0.005209	3.31
14	0.002525	0.008282	2.08
16	0.004016	0.013172	1.31
18	0.006390	0.020959	0.823
20	0.010152	0.033299	0.517
22	0.016142	0.052946	0.325

Figure 3 - Resistance per unit length of some common wire gauges.

By limiting the loop resistance to 5-percent of the loudspeaker's impedance, the level change due to line loss will be limited to 0.5 dB, since

$$dB_{loss} = 20\log\left(\frac{95}{100}\right)$$

$$dB_{loss} = -0.45\, dB$$

Line losses may be calculated by using the Syn-Aud-Con Slide Rule or the Syn-Aud-Con System Design Spreadsheet. Both are included in the course materials for Syn-Aud-Con Seminars.

Damping Factor

A loudspeaker cone has both mass and inertia, and like any moving body it tends to oppose any action to brake its motion. Damping factor is an indicator of how well an amplifier can damp the tendancy of a loudspeaker to ring after the cessation of a stimulus.

A simple experiment illustrates the concept[2]. Take a 12" or 15" woofer and sharply press-in on the cone. It should move easily. "Thump" it with your finger and note the cone motion. Now, short the terminals on the woofer and repeat the experiment. You will notice that the cone is much harder to displace, and doesn't "ring" as much when "thumped." Shorting the terminals has allowed the loudspeaker to damp itself by the current generated in the voice coil by the motion of the cone. This "back EMF" is useful for reducing the tendancy of a cone driver to ring. An amplifier with a very low output impedance can perform the same function as the short. The *damping factor* of an amplifier/loudspeaker combination is formed by the ratio of the loudspeaker's impedance to the amplifier's output impedance. Numbers in the hundreds are often quoted on spec sheets, but in the real world the resistance of the loudspeaker cable must be included with the amplifier's output impedance. Excessive cable resistance effectively offsets the "short" between the loudspeaker terminals presented by the amplifier. In practice, the *five-percent rule* for calculating the wire gauge will produce a damping factor of about 20 - more than sufficient for sound reinforcement systems. Figure 4 illustrates the reduction of damping in an extreme case that produced a subtle (but measurable) audible change in woofer performance.

"Good Sounding" Wire

Changes in sound quality are often attributed to the loudspeaker cable. Frequency-dependent level changes can be caused by the wire resistance. This is due to the complex nature of a loudspeaker's impedance[3].

Figure 5 shows the impedance curve of a loudspeaker in a tuned-box. Note that the impedance is a function of frequency. As shown earlier, the amplifier/loudspeaker interface is of the constant-voltage type. This means that the voltage delivered to the loudspeaker by the amplifier will be largely independent of frequency. Therefore the current drawn by a loudspeaker will depend upon the magnitude of the impedance at any given frequency, and increased current will be supplied to the loudspeaker at "low spots" on the impedance curve, resulting in greater input power to the loudspeaker. An increase in resistance caused by the loudspeaker wire will have a greater effect on power drawn at "low spots" on the curve than at peaks. This can cause a frequency-dependent change in what is heard by the listener. Since the power redu-

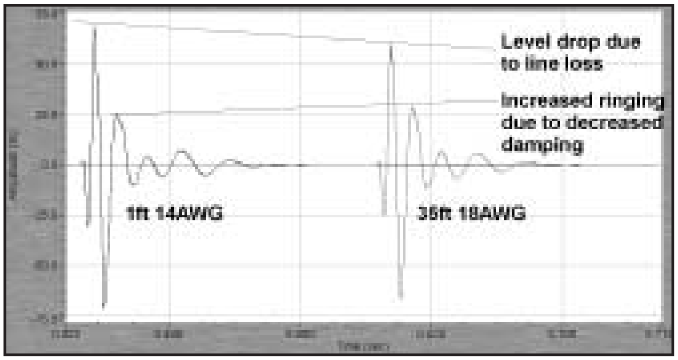

Figure 4 - The response of a 12" woofer to an impulse using two different wire gauges.

tion is greatest in the low-mid region (usually the lowest impedance region of the curve), the subjective impression is that of "tighter" bass response. As with damping factor, following the five-percent rule when calculating the required wire gauge will minimize such changes.

Other Issues

There are other issues that determine the best cable type for an application.

- It is usually advantageous to use **stranded wire** rather than solid. The reasons are more practical than audible - solid wire is more difficult to pull and terminate.

- **Twisted-pair wires** offer the advantage of reduced magnetic field radiation into other wires or nearby equipment.

- The **jacket material** must have the proper fire rating to assure that it doesn't emit noxious fumes when burnt. Consult the code books before specifying wire!

Conclusion

The most significant aspect of the amplifier/loudspeaker interface is the loudspeaker wire, and the most significant parameter of the wire is its resistance. It's always better to use shorter wire of larger diameter to minimize this resistance.

Other factors such as capacitance and inductance can affect the performance of a system if they get out of control. I urge the reader to test the significance these effects for themselves rather than relying on the conclusions or claims of others. Much confusion can arise from exaggerating the significance of wire parameters.

The amplifier/loudspeaker interface is but one of many interfaces in an audio system. The *five-percent rule* provides a useful metric for assuring that it is not degraded by excessive wire resistance.

References:

[1] The ARRL Handbook for Radio Amateurs p. 6.23 - Seventy-seventh edition 1999

[2] Testing Loudspeakers by Joseph D'Appolito

[3] Sound System Engineering Second Edition by Don and Carolyn Davis

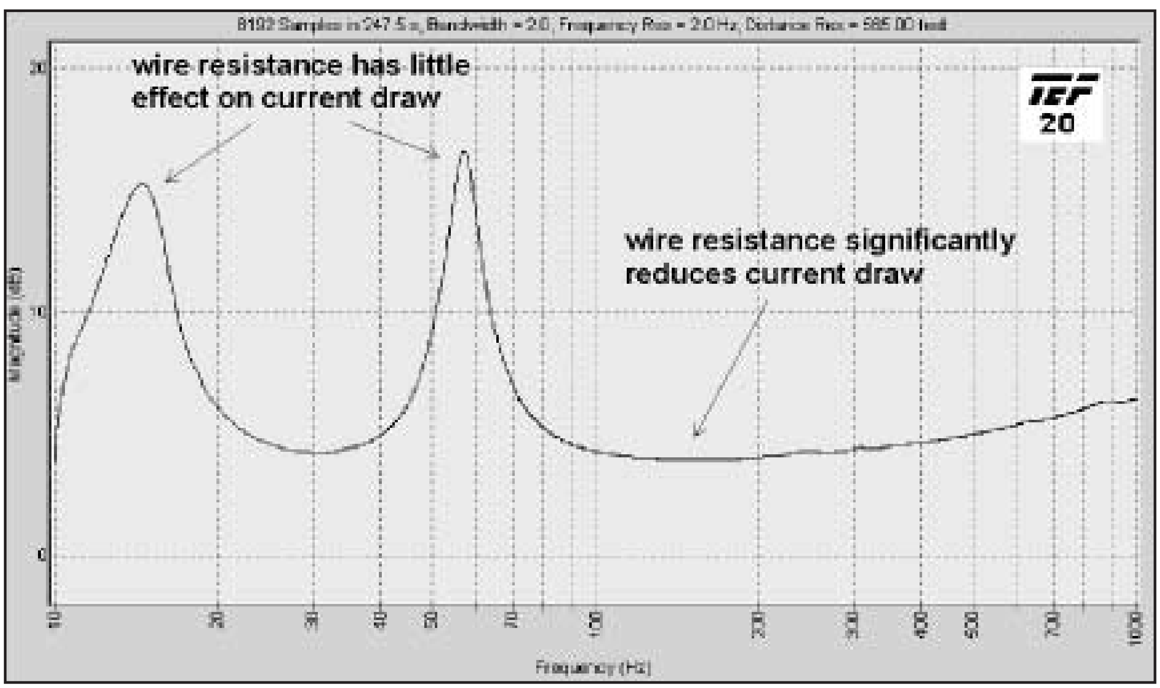

Figure 5 - The impedance of a loudspeaker is a complex function of frequency. The current drawn by a loudspeaker will follow the inverse of the impedance curve. Wire resistance can affect the current drawn in a frequency-dependent manner, affecting the spectral balance heard by the listener.